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블라인드 처리 항목	**1. 저자소속 등 인적사항** - 지원자 본인뿐만 아니라 모든 저자의 소속, 이메일(출신학교 노출 가능) - 교신저자 등 별도로 기재된 소속, 연락처, 이메일 - 저널에 따라 페이지 상/하단에 기재된 저자정보(인적사항, 성명) **2. 사사문구(acknowledgments)** **3. 학위논문 내 학교 워터마크(watermark)** **4. 첨부파일 명칭은 게재논문(1), 게재논문(2)와 같이 변경** - 첨부파일 명칭에 이름 등의 개인정보를 포함하지 않도록 유의
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※ 블라인드 처리 샘플 참조

[블라인드 처리 샘플(논문초록)]

블라인드 처리 샘플(논문)

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Full paper

High efficiency perovskite light-emitting diodes of ligand-engineered colloidal formamidinium lead bromide nanoparticles

저자 이름 : 블라인드 처리

[redacted]

저자 소속 : 블라인드 처리

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ABSTRACT

Formamidinium (FA, $CH(NH_2)_2$) lead bromide perovskite ($FAPbBr_3$) nanoparticles (NPs) are promising emitters due to their high stability and ability to emit pure green color in both film and solution states. Even though various types of metal halide NP emitters in solution have shown high photoluminescence quantum efficiencies (PLQEs), electroluminescence efficiencies of the light-emitting diodes (LEDs) using the NP films are still much poorer, possibly due to the insulating ligands which can impede the charge injection and transport in films. Therefore, the organic ligand of NPs should be designed to facilitate charge injection and transport in LEDs. Here, we synthesize ligand-engineered colloidal $FAPbBr_3$ NPs at RT and demonstrate high efficiency perovskite NP LEDs based on the $FAPbBr_3$ NPs. Control of ligand length reduces trap-assisted recombination of carriers at the surface traps, and thus maximizes the PLQE of $FAPbBr_3$ NPs. Ligand engineering can also improve the charge injection and transport capability in $FAPbBr_3$ NP films. With this ligand engineering method, we achieve maximum current efficiency of 9.16 cd/A in LEDs based on $FAPbBr_3$ NPs, which is the highest efficiency in $FAPbBr_3$ NP-LEDs to date. The ligand engineering method reported here can be a simple way to improve the luminescence efficiency of optoelectronic devices based on perovskite NP LEDs.

1. Introduction

Organic-inorganic hybrid perovskite (OIP) materials are promising emitters due to widely-tunable emission wavelength (400 nm≤λ≤780 nm), high color purity with narrow full width at half maximum ((FWHM) ~ 20 nm) and low material cost [1–10]. Furthermore, their solution-processability as polycrystalline bulk films has allowed a rapid increase in electroluminescence (EL) efficiency from 0.1% of exterial quantum efficiency *EQE* to 11.7% in only three years by reducing perovskite grain size or by incorporating various organic ammonium moieties in their crystals [1–10]. Nevertheless, polycrystalline bulk films of OIPs still need to overcome low photoluminescence quantum efficiency (PLQE) at low excitation density ($< 10^{20}$ cm^{-3}), and low EL efficiency at low current density, due to low radiative recombination rate of electron-hole pairs under these conditions [1–7,11].

Colloidal OIP nanoparticles (NPs) can be another form of OIP emitters that can achieve high EL efficiency by efficiently confining the exciton in perovskite NPs (≤20 nm) [1,11]. Recently, bright-green-emitting colloidal OIP-NPs based on methylammonium (MA, CH_3NH_3) lead bromide ($CH_3NH_3PbBr_3$) have been demonstrated and high PLQE (~90%) have been achieved [11,12]. Furthermore, their simple synthesis process at room temperature (RT) showed great possibility for wide use in industry [11,12]. However, EL device made of the colloidal $MAPbBr_3$-NPs still showed much poorer EL efficiencies (current efficiency *CE*~11.49 cd/A and *EQE*~3.8%) [13] than did $MAPbBr_3$ polycrystalline bulk film-based light-emitting diodes (LEDs) (*CE*~42.9 cd/A and *EQE*~8.53%) [2] possibly due to inefficient charge injection and transport though the insulating ligand. Furthermore, MA cation can reduce the stability of the perovskite crystal under heat, moisture and light [14], so $MAPbBr_3$-based colloidal perovskite NPs are not sufficiently stable.

저자 이름, 저자 관련 정보(E-mail, 연락처) : 블라인드 처리

* Corresponding author.
[redacted]

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